

Development of a Novel Gas Pressurized Stripping (GPS)- Based Technology for CO₂ Capture from Post-Combustion Flue Gases DE-FE0007567

Carbon Capture Scientific, LLC.

CONSOL Energy Inc.

Nexant Inc.

Western Kentucky University

HiGee USA Inc.

Presented by Shiaoguo (Scott) Chen

DOE Carbon Capture Technology Meeting, July 8-11, 2013, Pittsburgh, PA



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About Carbon Capture Scientific, LLC

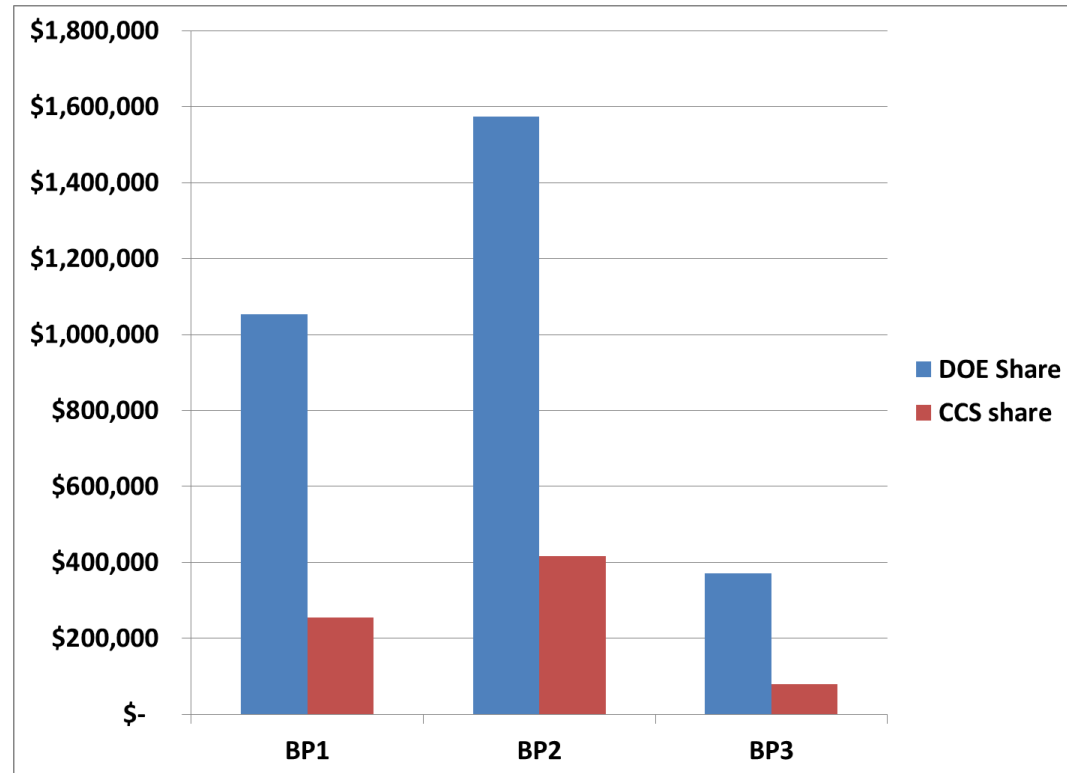
- ❑ Early stage company located in Pittsburgh, PA
- ❑ Two patent granted/pending CO₂ capture technologies
- ❑ Bench-scale development funded by the Department of Energy / National Energy Technology Laboratory
- ❑ Chemical Engineers/Scientists with strong expertise in process design, simulation and optimization
- ❑ Technology development based on transition from thermodynamic analysis, to process simulation, to bench scale prototyping
- ❑ Continuing to make key hires to build in-house expertise for current and future large scale projects

Project Budget (Revised)

	Budget, \$
DOE	2,999,756
CCS	751,178*
Total	3,750,934

*including cost share from CONSOL Energy Western Kentucky University, and HiGee USA

(Cost share is ~20%)



DOE funding and cost share on a yearly basis

Project Team and Focus (Revised)

DOE/NETL

- Andrew Jones, NETL project manager

Carbon Capture Scientific, LLC

- Computer simulation to optimize GPS based process for existing power plants
- Bench-scale experiments to obtain process design data for GPS based process

CONSOL Energy Inc.

- Work with CCS to acquire phase equilibrium and related process design data

Nexant Inc.

- Conduct techno-economic analyses for the GPS based technology

Western Kentucky University (WKU)

- Consult on thermal and oxidative properties; Corrosion effects and physical property measurements

HiGee USA

- Commercial source for low cost capital equipment (Rotating Packed Bed)

Exceptionally Rapid Progress: Milestones Achieved On or Ahead of Schedule

- ❑ GPS column study and optimization demonstrates thermal efficiency of 60% or greater (BP1)
- ❑ Solvent loss due to degradation of solvent less than 3 kg/ton CO₂ (BP1)
- ❑ Overall energy performance column and solvent less than or equal to 0.22 kwh/kg CO₂(BP2)
- ❑ GPS column efficiency experimental measured at 50% or greater (BP2)
- ❑ Overall energy performance of system less than or equal to 0.20 kwh/kgCO₂(BP3)
- ❑ Increase in capital equipment costs of less than or equal to 20% over existing process(BP3)

Rapid Progress Results in Revisions to Team and Work Plan

- ❑ Commercial Rotating Packed Bed (RPB) equipment offers promise of significant reduction in capital costs
- ❑ Added RPB supplier (HiGee USA) to team and began evaluation of RPB in laboratory
- ❑ Conducted lab scale RPB experiments to provide design data for the skid mounted system
- ❑ Results in two possible equipment solutions: traditional column-based GPS system and RPB-based system
- ❑ Constructing a skid mounted system for testing of column-based and RPB-based GPS systems
- ❑ Plan to test above systems at NCCC with coal-derived flue gas stream

Revised Project Objectives Focus on NCCC Testing and Alternatives to Reduce Capital Costs

- ❑ Test individual process units at the bench-scale in order to document experimental results and prepare for transition to pilot scale
- ❑ Perform computer simulations to maximize the benefit of the GPS technology for existing power plants
- ❑ Use commercial solvents in evaluation of GPS system in order to minimize the economic risk of the proposed technology
- ❑ Perform bench-scale testing of a rotating packed bed (RPB) system in order to reduce capital costs of GPS
- ❑ Design, build, and operate a bench-scale skid system to evaluate both conventional column-based GPS and RPB-based GPS systems at the National Carbon Capture Center (NCCC).

Revised Project Schedule: Oct.1, 2011 – Sept.30, 2014

Tasks	Task Duration												Task Focus	Performer						
	1-12 BP1				13-24 BP2				24-36 BP3					CCS	HiGee	CONSOL	Nexant	WKU		
Task 1. Project planning & management														N/A	X					
Task 2. GPS column study and its optimization				A										Process	X					
Task 3. Optimization of GPS process for existing plant						C								Process	X					
Task 4. Simulations of Alternative Separations method for GPS stripping gas														Process	X					
Task 5. Phase equilibrium data measurement														Solvent	X			X		
Task 6. First absorption column testing														Process	X			X		
Task 7. GPS column design/fabrication and testing						D								Process	X			X		
Task 8. Second absorption column testing						E								Process	X			X		
Task 9. Stability of solvent at high loading and high T				B										Solvent	X					X
Task 10. Corrosion test at high loading and high T														Solvent	X					X
Task 11. RPB unit evaluation at CCS Laboratories														Equipment	X	X		X		X
Task 12. Survey of EH&S of GPS process														Solvent	X					
Task 13. Preliminary techno-economic analysis														Economics					X	
Task 14. Revision of techno-economic analysis						F								Economics					X	
Task 15. Updated techno-economic analysis														Economics					X	
Task 16. GPS system design/fabrication and testing														Process	X	X				
Task 17. RPB based GPS system														Equipment	X	X				

Revised Milestones for BP2

Task #	Description	Planned Completion Date	Comments
16	Complete design of bench-scale GPS test unit for conventional and RPB-based operation	4/30/2013	Completed
1	Host site agreement executed	6/30/2013	Completed
16	Complete shakedown testing of the column-based GPS bench unit on simulated flue gas	6/30/2013	Slightly Delayed
11	Delivery of enhanced bench-scale RPB-based absorption and stripping units to CCS LLC	7/31/2013	On Track
16	Complete installation of 500 SLPM column-based GPS bench unit at NCCC	7/31/2013	On Track
16	Complete bench unit start-up and demonstrate plant operation at steady state	8/31/2013	On Track

BP1 Tasks: All Completed on Schedule

Task #	Description	Simulation / Experiment	Comments
2	GPS column study and its optimization	Simulation	Completed
5	Phase equilibrium data measurement	Experiment	Completed
6	First absorption column testing	Experiment	Completed
9	Stability of solvent at high loading and high T	Experiment	Completed
13	Preliminary techno-economic analysis	Simulation	Completed

BP2 Tasks: Rapid Progress Results in Revisions

Task #	Description	Simulation / Experiment	Comments
3	Optimization of GPS process for existing plant	Simulation	Completed
4	Simulation of alternative separation for GPS stripping gas	Simulation	Completed
7	GPS column design/ fabrication and testing	Experiment	Completed
8	Second absorption column testing	Experiment	Completed
10	Corrosion test at high loading and high T	Experiment	In process / on schedule
11*	RPB unit evaluation at CCS Laboratories	Experiment	In process / on schedule
14	Revision of techno-economic analysis	Simulation	In process / on schedule
16*	GPS system design/ fabrication and testing	Experiment	In process / on schedule

* Revised or new task for BP2

Task 3: Overall Energy Performance of Column and Solvent ≤ 0.22 kWh/kg CO₂

Overall energy performance of the GPS process:

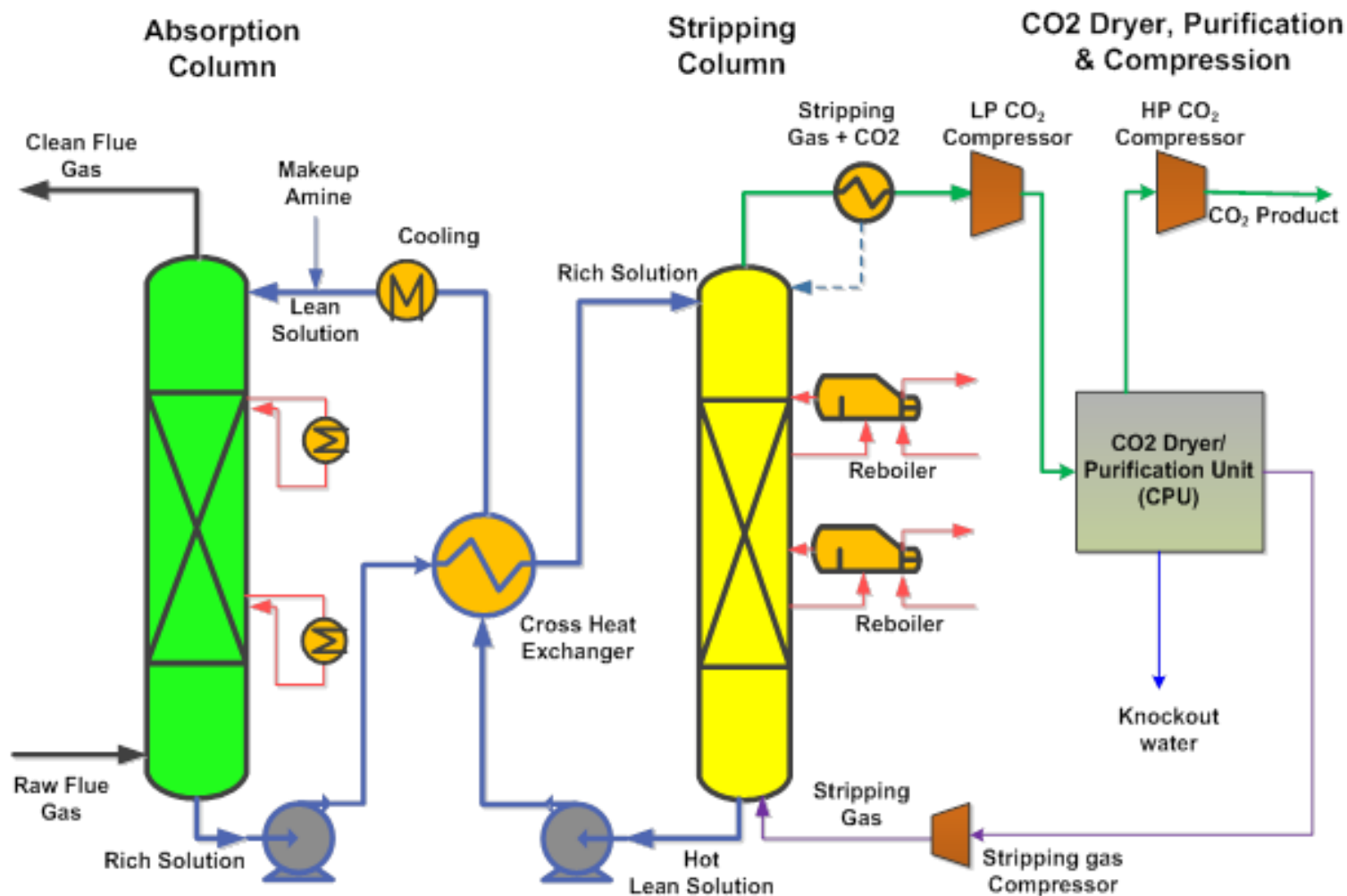
Capture percentage, %	90.20
Product flow rate, kmol/hr	13,112
Product pressure, bar	153
Heat requirement (electricity equivalent), kWh/kg CO ₂	0.131
Electricity need, kWh/kg CO ₂	0.065
Overall energy performance, kWh/kg CO ₂	0.196

CO₂ Specifications for GPS based CO₂ capture process:

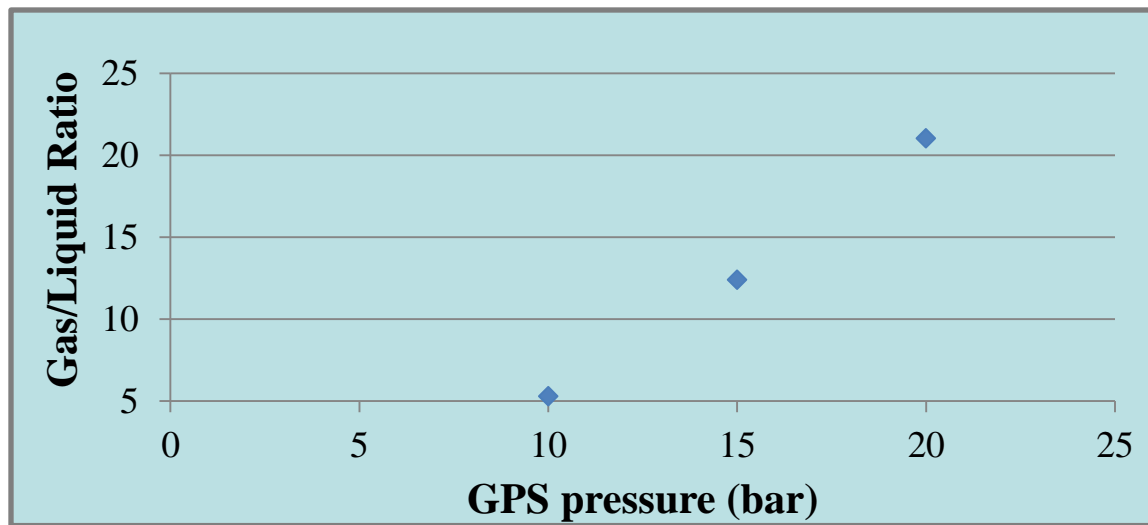
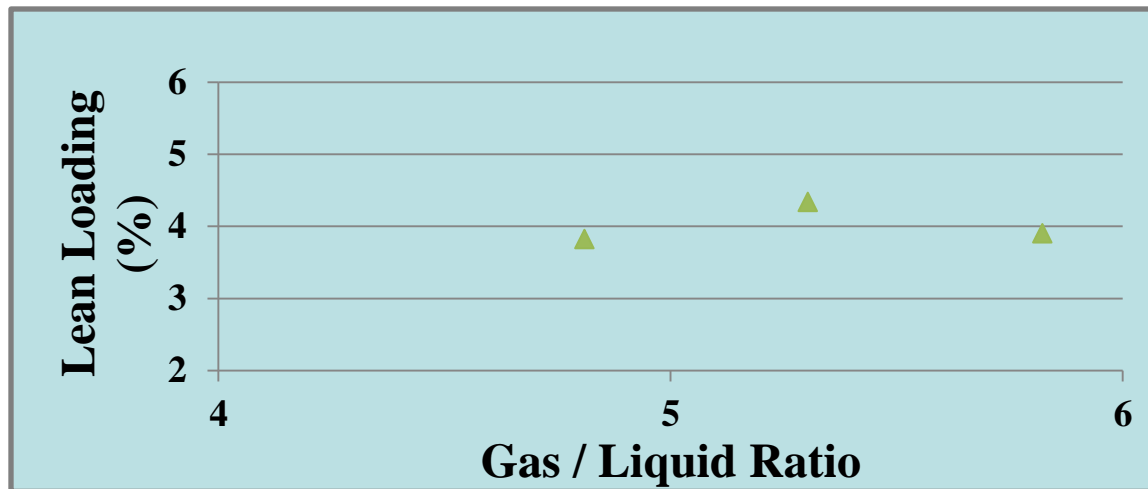
Product compositions:	%mol
CO ₂	97.63
H ₂ O	0.24
N ₂	2.13

Achieved milestone of energy performance column and solvent ≤ 0.22 kWh/kgCO₂

Task 4. Simulations of Alternative Separations method for GPS stripping gas



Task 7: GPS Column Design/ Fabrication and Testing



Task 7: GPS Column Thermal Study/Milestone

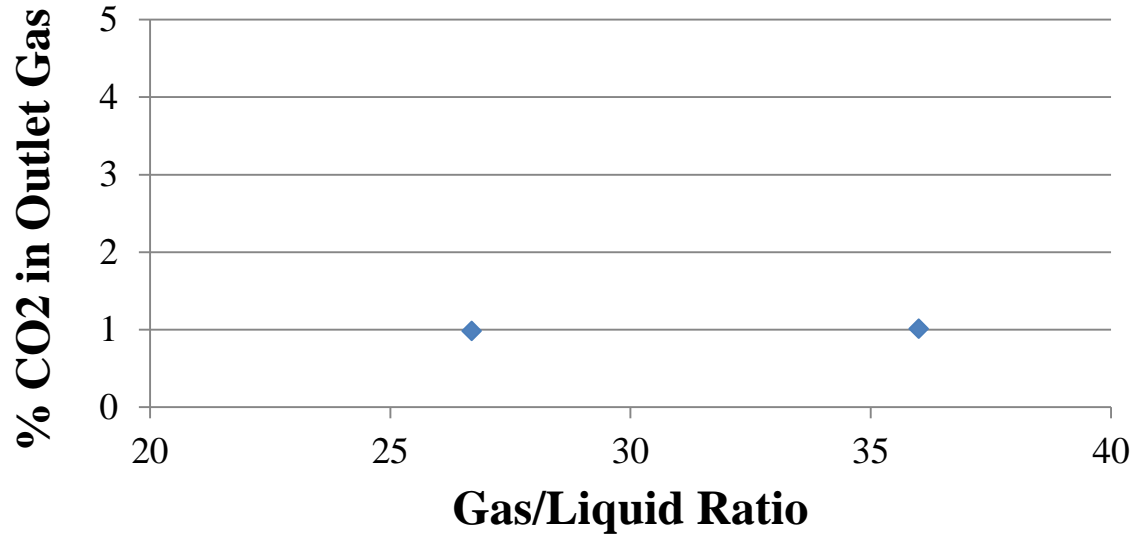
Run	1	2	3	4	5	6
liquid flow rate (g/min)	74.4	65.5	115	115	110	110
Heat GPS (W)	93.9	83	154.9	192.7	137	146
Sensible Heat (W)	29.0	25.5	64.1	96.1	48.9	73.5
Reaction + Stripping (W)	64.9	57.5	90.8	96.6	88.0	72.5
Equivalent Reaction + Stripping (KJ/Kg CO2)	1377	1386	1248	1327	1266	1042
Theoretical Minimum	818					

$$\Delta H_{min} = R \frac{T_2 T_1}{T_2 - T_1} \ln (P_2 / P_1)$$

$$\frac{\Delta H_{min}}{\Delta H_{exp}} = \frac{818 \text{ kJ/kg CO}_2}{1274 \text{ kJ/kg CO}_2} = 64\%$$

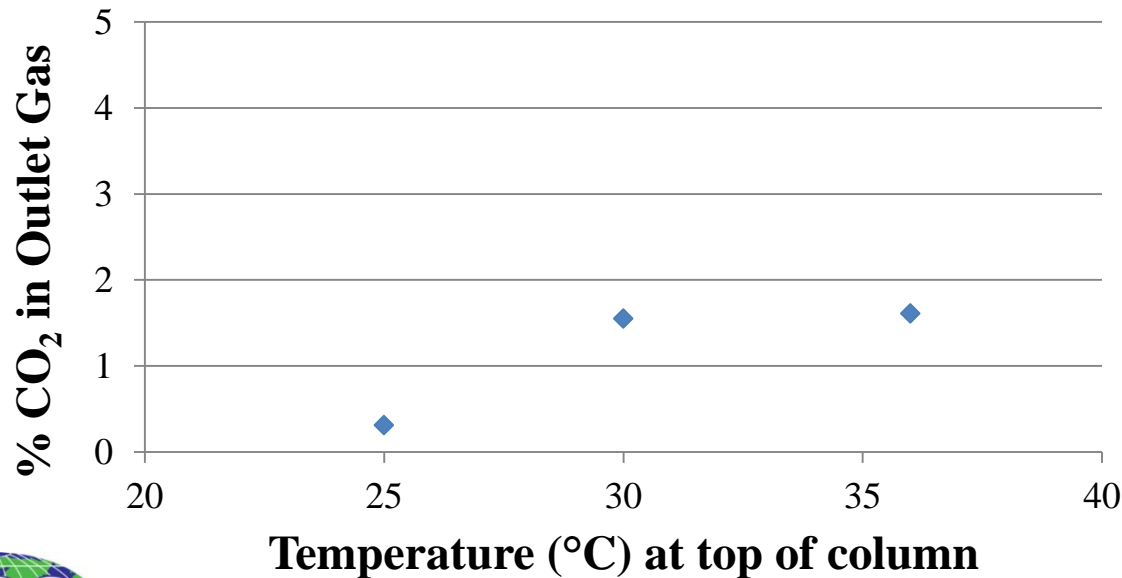
**Experimentally observed
GPS operations achieving a
thermal efficiency of 64%
(milestone of 50%)**

Task 8: Second Absorption Column Testing



Second absorption can easily achieve CO₂ concentration required for the GPS operations (much less than 10% CO₂)

- Simulation studies show that 2nd adsorption column can be replaced with a compound of compression and refrigeration processes
- Compound compression and refrigeration process improves energy efficiency, while still maintaining high purity CO₂ product.



Task 10: Corrosion Testing

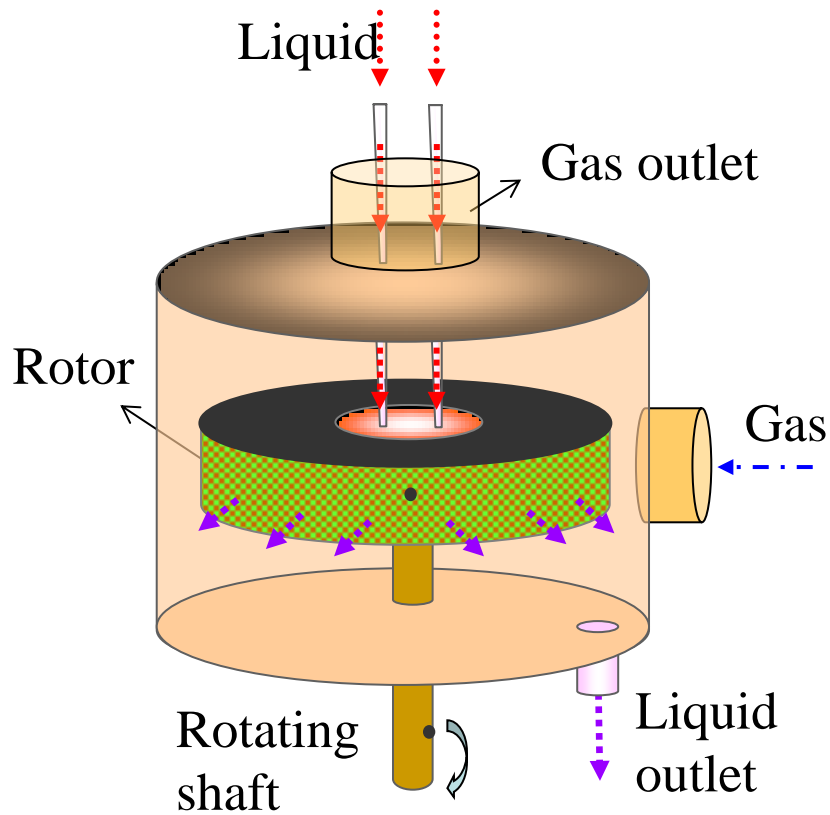
$$k = \frac{\textit{weight lost}}{\textit{surface area} * \textit{density} * \textit{exposure time}}$$

CCS Solvent

	Rich solvent			Lean solvent					Lean Solvent with O2	
	20 C	50 C	80 C	20 C	50 C	80 C	100 C	110 C	20 C	50 C
Stainless 304L	0.032	0.044	0.08	0.031	0.097	0.058	0.306	0.961	0.011	0.048
Stainless 316 L	0.109	0.025	0.254	0.013	0.046	0.072	0.279	0.84	0.053	0.057
Carbon Steel	0.024	0.035	0.114	0.033	0.035	0.27	0.363	1.23	0.035	0.197

Task 11. Rotating Packed Bed (RPB) Unit Evaluation

Schematic of RPB

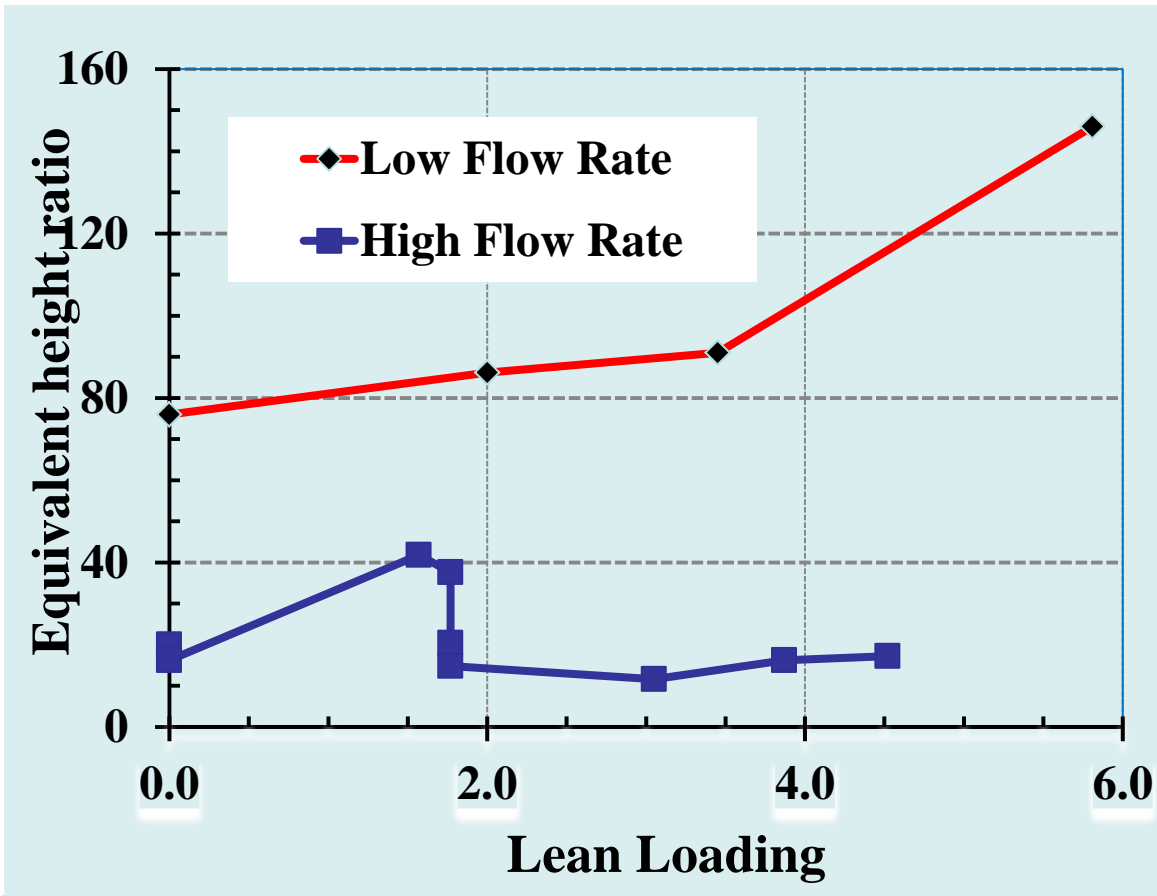


Commercial RPB



Task 11. RPB Unit Evaluation at CCS Laboratories

Equivalent Height Ratio=
Equivalent Column packing height/RPB packing height



Task 14. Revision of Techno-economic Analysis

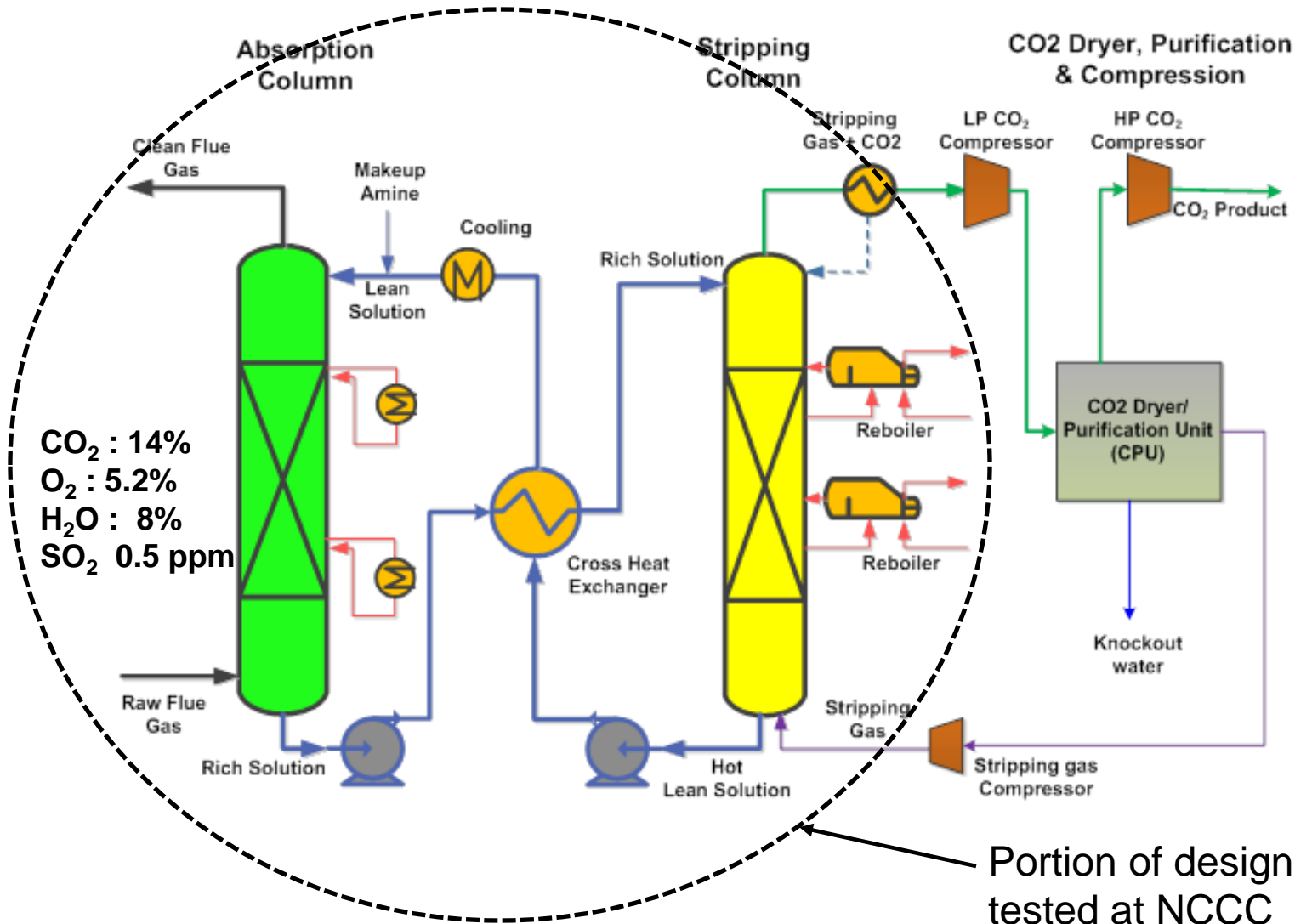
	Baseline Case 12	GPS 20% Recycle	GPS/Refrigeration
Total Output at Generator Terminals, kW	663,445	753,660	761,644
Auxiliary Load Summary, kW:			
Coal Handling and Conveying	490	490	490
Limestone Handling & Reagent Preparation	1,270	1,270	1,270
Pulverizers	3,990	3,990	3,990
Ash Handling	760	760	760
Primary Air Fans	1,870	1,870	1,870
Forced Draft Fans	2,380	2,380	2,380
Induced Draft Fans	10,120	10,120	10,120
SCR	70	70	70
Baghouse	100	100	100
FGD Pumps and Agitators	4,250	4,250	4,250
Misc Balance of Plant	2,000	2,000	2,000
Steam Turbine Auxiliaries	400	400	400
Condensate Pumps	630	630	630
Cooling Water Circulation Pumps **	12,260	15,476	15,476
Cooling Tower Fans	6,340	4,459	4,459
Transformer Losses	2,300	2,613	2,613
Amine CO ₂ Capture Plant Auxiliaries	21,320	22,243	22,568
CO ₂ Compression	46,900	33,828	34,100*
Total Auxiliaries, kW	117,450	106,949	107,546
Net Power Export, kW	545,995	646,711	654,098
Net Plant Efficiency, % HHV	27.2	32.2	32.6
Net Plant Heat Rate, Btu/kW	12,536	10,584	10,464

*was calculated based on 5C of DOE oxyfuel report

Task 14. Revision of Techno-economic Analysis

Type of CO ₂ Capture Technology	Case 11 (No Capture)	Case 12 (MEA Baseline)	GPS with 20% Recycle	GPS Refrigeration
Power Production, MW				
Gross Power	580	663	754	762
Net Power	550	546	647	654
Capital Cost, \$MM				
Power Plant	866.4	1109.9	1123.7	1123.7
PCC Plant	0.0	410.8	470.9	447.5
CO ₂ Compression and Drying	0.0	46.4	55.0	75.8
Start Up Costs (2% TPC)	15.5	26.4	27.6	27.7
Total Capital Cost, \$MM	881.9	1,593.5	1,677.3	1674.7
Operating Cost excl Fuel, \$MM/yr				
Fixed Operating Cost	13.8	20.5	22.9	22.9
Variable Operating Cost				
Non PCC related Opt Cost	20.0	33.6	35.6	35.6
NaOH		0.9	0.9	0.9
H ₂ SO ₄		0.3	0.3	0.3
Amine M/U		1.0	1.1	1.1
Active Carbon		0.6	0.5	0.5
Corrosion Inhibitor/Solvent MU		0.0	0.0	0.0
Total Operating Cost excl Fuel, \$MM/yr	33.8	56.9	61.3	61.3
Fuel Cost, \$MM/yr	64.5	92.0	92.0	92.0
LCOE (excl CO₂ TS&M), mills/kWh	63.9	112.0	98.7	97.6
% of Case 11 LCOE - Compare to 2007	100%	175%	154%	153%

Task 16. GPS System Design/Fabrication and Testing



Summary of Progress

- ❑ **Project ahead of original schedule**
- ❑ **Key energy related milestones achieved – demonstrates improvements over existing capture technologies**
- ❑ **Rapid progress resulted in revising work plan and budget in order to add testing at NCCC**
- ❑ **Additional lower cost capital equipment alternative added – Rotating Packed Bed (RPB)**
- ❑ **Progress of revised project on schedule**

Future Work

- ❑ BP2: Perform parametric testing of column-based GPS system at NCCC
- ❑ BP3: Perform parametric testing of RPB-based GPS system at NCCC

Task	Description	Simulation / Experiment
12	Survey of EH&S of GPS process	Documentation
15	Updated techno-economic analysis	Simulation
17	RPB based GPS system	Experiment

❑ Prepare for Pilot Scale Tests

- Process design data for GPS based technology
 - Column Based
 - RPB based